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EKONO CONSULTING ENGINEERS
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348 SKINNER BLDG.
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Howard Edde

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Design and Operation of Aerated Lagoons for Municipal Wastewater Treatment in Cold Climates

by

Howard Edde

EKONO Consulting Engineers

Seattle, Washington - Helsinki, Finland
Vienna, Austria

Introduction

The aerated lagoon method of wastewater treatment is primarily a product of the 1960's. Although aerated lagoon experiments were started for industrial aplications in 1957, it was the 1960's when aerated lagoons became recognized as valid systems for the treatment of municipal effluents.

It was Weston (1), Eckenfelder and O'Conner (2) and McKinney and his co-workers (3,4) who were among the first to realize and take advantage of aerated lagoons. Initially, diffused aeration was used, being a carry-over concept from traditional design of municipal activated sludge units, but this often did not best lend itself to large aeration cells. The industry related aerated lagoon developments tended toward mechanical surface aeration devices which achieved a better balance between mixing and oxygen transfer.

Figure 1 shows the first real aerated lagoon for the treatment of municipal effluents which was constructed in a Kansas City, Missouri subdivision and designed to treat the sewage from a shopping center and surrounding subdivision. This installation used a floating mechanical surface aeration unit designed to keep a constant level of submergence with a constant oxygen transfer rate. During the initial winter of operation ice buildup resulted in increased weight to the aerator and increased submergence. The oxygen transfer rate was substantially reduced and a fixed platform, as shown, was constructed to replace the original floating platform where ice was a problem.

Once it became evident that aerated lagoons could produce a reasonable BOD reduction efforts were directed toward producing the highest effluent quality possible while maintaining consistant operational performance. This led to a better understanding of mixing significance, temperature effects, series cell vs. parallel cell flow pattern, biological sludge accumulation and other special design features of this new concept of low cost treatment of domestic wastewaters.

In the midwestern United States this domestic wastewater treatment method was rapidly accepted with better design features incorporated into each new installations, such as the unit pictured in Figure 2, and stories of the success of this new idea became widespread. It soon became recognized that despite the many very attractive features of this new idea, it also had several limitations. One of the most obvious of these was the effect of seasonal climatic changes, which will be discussed in detail later, on the treatment efficiency and system reliability.

The effect of climatic conditions is especially significant in the colder Northern regions where ice problems, which appeared in the first installation treating domestic wastewaters, become serious and have threatened the very idea of aerated lagoons as a practical method of biological treatment in these climates. Unfortunately, many of these icing difficulties arose from an overly rapid acceptance of this new idea with field installations designed and put into operation lacking proper consideration for protection against adverse weather conditions.

The first aerated lagoon in Alaska, constructed in 1967 was located at the Eielson Air Force Base near Fairbanks (5) and operated by the Arctic Health Research Center. This installation will be discussed in detail during this seminar. By 1970, there were at least 17 aerated lagoons in Alaska. All except one of these units were using perforated tubing diffused aeration for oxygenation and mixing. This aeration method was largely accepted to prevent reoccurance of the bad icing experiences reported with mechanical surface aeration at other Northern installations, notably in Canada and the North Central United States.

With regard to differences among biological treatment processes operating in cold climates the most important factor from a biological point of view is the effect of temperature upon the rate of biological reactions. Normally, in all biological processes these reactions increase with temperature to an optimum value, approximately 37°C for most aerobic systems, beyond which the reaction rate of mesophilic organisms decreases (20). However, the magnitude of the temperature effect depends upon the nature of the process treatment modification applied.

The long detention time and low biological solids concentration in aerated basins has the disadvantage that the system is more influenced by changes in temperature than is the activated sludge method. The temperature effect on the reaction rate can be expressed by the relationship:

$$\frac{K_t}{K_{20}} = \theta^{(t_2 - 20^oC)}$$

The absolute temperature dependency on the process can be shown by the following values of θ where F/M is the applied food to microorganism loading ratio (6):

		θ
Activated sludge	(F/M < 0.5)	1.00
	(F/M > 0.5)	1.00-1.04
Aerated lagoons		1.035
Aerated aerobic-faculative lagoon		1.07

These data indicate that the more dispersed growths found in the lower biological reaction rate aerated lagoon process are more directly affected by changes in temperature than is the flocculant biological growths found in the activated sludge system. The reasons for this can be explained as follows. In the activated sludge process at low loadings, BOD removal and oxidation depend on diffusion of oxygen into the biological flocs, where it is subsequently utilized. At low temperatures, a low oxygen utilization rate permits greater diffusion of oxygen, and consequently a large portion of floc is aerobic. At high temperatures, the high respiration rate depletes the oxygen rapidly and only a small portion of the floc is aerobic. It can be assumed that a large mass of organisms at a low respiration rate (winter) achieves the same degree of oxidation as a small mass at a higher respiration rate (summer), and hence, the coefficient θ is approximately 1.0.

By contrast, at high organic loadings, the floc tends to become dispersed (bulking sludge) and each organism is more directly affected by changes in temperature. The coefficient θ therefore increases. Likewise, in aerated lagoons, at a low solids level, the organisms are more dispersed, and the temperature coefficient is high. Marked improvement in aerated lagoon operation is possible during the winter months by adding a recycle and increasing the solids level in the basin.

Land requirements for aerated stabilization basin treatment lie between those for activated sludge aeration tanks and natural storage stabilization basins. Thus while land usage for aerated basins may equal 2 acres/million gal/day, which is much greater than a typical requirement of 0.04 acre/million gal/day for activated sludge tanks, it is substantially less than the 40 acreas/million gal/day normally allotted for natural stabilization basins.

Since the aerated lagoon is still a relatively new process, especially when operated under unusual climatic conditions, many regulatory agencies have continued to consider them as experimental facilities and felt it first necessary for each particular installation to operate with conditional approval for a trial period of sufficient time to insure satisfactory operation before an operating permit is issued. For example, after a few ponds were approved in Minnesota the approval of additional ponds was withheld as recent as 1970 in order to determine the feasibility of this type of system (8).

Similarly, in Winnipeg, the Metropolitan Corporation in 1967 undertook a study of aerated basin feasibility when operating in Canadian Prairie winter conditions (9). This study, besides making a strong case against surface aerators, pointed out the larger sludge accumulations during cold weather operation even to an extent of causing reduced BOD removal during the summer months because of benthal oxygen demands on the system.

Types of Installations and Advantages/Disadvantages

The term aerated lagoon is a general description, applying to a variety of processes. The variety results because in the conversion of oxidation ponds to aerated lagoons different engineers applied varying degrees of artificial mixing and oxidation to solve the problems of overloaded oxidation ponds.

Shown in Figure 3 are three distinctly different types of aerated lagoons (19):

The completely mixed aerated lagoon is an activated sludge aeration basin without sludge return where all solids are maintained in suspension. All organic stabilization is dependent upon the suspended bacterial solids. Oxygen is machine derived and algae are not apparent.

The facultative aerated lagoon has a degree of mixing which permits heavier solids to settle in the lagoon while biologically treating suspended and soluble organics in the liquid portion. The oxygen transfer is primarily associated with the surface aerator itself. Algae may be present in small numbers but play only a small or insignificant role in the oxygen supply.

The aerated oxidation pond is essentially a high rate oxidation pond. Mixing and aeration equipment is added to an existing overloaded oxidation pond, distributing the high oxygen concentration near the surface throughout the pond contents. Oxygen is primarily transferred by algae except during cold months.

From the time of the very first aerated lagoon installation, attempts have been made to modify the aerated basin idea. In fact, for treatment of industrial as well as municipal wastewater, the aerated lagoon since its inception has constituted the engineers attempt to do a job previously assigned to natural surface reaeration and photosynthetic algae activity. Often this has been an effort to regulate and mix throughout the entire basin contents the dissolved oxygen residual as well as dissolve more oxygen in the waste than can natural reaeration or algae alone. In accomplishing these ends the engineer found himself destroying the algal-bacterial symbiotic system of the oxidation pond and replacing it with a low-level form of activated sludge (10).

Once the basin was proved to work for treatment of municipal sewage at the original Kansas City installation a series of short retention ponds were placed in operation following the aerated section. No longer could the aerated lagoons be considered an intermediate treatment. The effluent quality from the tertiary ponds was more a function of the algae growth in the ponds themselves rather than to untreated waste or bacteria, but largely a high quality effluent was produced.

The concept of an approximately one day detention section with a relatively high aeration intensity completely mixed section with regards to oxygen followed by a larger aerated pond appears to be sound process modification. Optimization procedures have been developed to establish the best relationship between the size of these two ponds especially in cold climate high heat loss situations.

Recognization develped that a minimum detention time exist below which process failure will result. Process failure occurs when the hydraulic washout rate of the bacteria exceeds the synthesis rate and thus is closely related to the influent feed concentration and biodegradation rate (11). With this theory as the basis, but unknown to many of the designers, attempts proceeded to improve performance by recycling treated effluent to the head end of the aeration pond. Since most of these field installations were of several days detention hydraulic washout rate was not limiting. The conclusion drawn from the field studies in these cases was often that recycling the treated effluent was to no avail. An understanding by the design engineer of the hydraulic washout rate concept fundamentals would have rendered needless the additional recycle equipment and associated expenses at many of these installations.

After aerated basins were becoming fairly popular, it was obvious that despite the good BOD removals effected, the dispersed bacterial growth in these systems resulted in a higher effluent suspended solids concentration than found in a well operated activated sludge plant. Although these solids were mostly inerts regulatory agencies soon began insisting on sedimentation facilities following the aeration section and in many cases it was required this be a mechanically cleaned clarifier. This and similar requirements have began to erode an attractive feature of the aerated lagoon, namely low initial construction cost.

When an aerated lagoon is constructed for operation in a cold climate special design precautions must be considered. The control of excessive heat loss to the atmoshpere is extremely important and suggest the design of deeper basins with a minimum of surface area where building conditions permit. In these cases basin depths of up to 20 feet or more are entirely practicle and in many cases desirable for optimum utilization of mixing energy, minimizing atmospheric heat loss, reducing land requirements, and providing bottom sludge storage accumulation volume (12).

Methods and materials of construction related to frost heave and ice action can present problems (5). Construction in permafrost should be given special consideration by engineers thoroughly familiar with embankment problem in this environment. In these cases melting of large ice lens under the retaining embankments can be disasterous as can spring thermal expansion of ice layers which can create considerable strain on embankments, especially vertical walls with large exposed areas. These ice layers can form to depths of greater than four feet on aerated lagoons (21). PVC and bentonite have in some cases been used to seal the lagoons.

Regarding minimization of heat loss, observations at Winnipeg (9) proved that to some extent the aeration cell has a built in self protection system. When the temperature rose to $5^{o}C$ the ice melted on 25 percent of the cell, but as soon as the temperature dropped the cell would cover with ice to conserve heat. It is useful the lagoon be shielded from the wind since this is very significant in the rate of heat loss.

Influent, cross-over, and effluent lines should be submerged, with the influent line centrally located and entering the basin in the immediate area of at least one of the aerators. The engineer should take advantage of the increased flexibility of multi-series cells by constructing the piping to permit any cell to be bypassed or drained for maintenance or repair purposes. Many aerated lagoons located in cold climates have an effluent discharge problem during the winter. A submerged discharge in the receiving water is desirable.

Although a strong case for perforated tubing aeration for cold weather aerated lagoon applications has been presented (21), as illustrated in Figure 4a, it is feasible to design other satisfactory aeration systems. Floating aerators have been successfully operated at Hinton, Alberta, and a fixed mounted surface unit such as in Figure 4c, has been successfully exposed to air temperatures of -29°C to -35°C at Prince George, British Columbia. However, both of these installations treated a relatively warm industrial effluent. Another unit called the air gun, which is a combination of diffused air and surface aerator principals is shown in Figure 4b.

The air gun unit compressed air is delivered into an inverted siphon in the gun base where a large bubble is formed which rises inside the gun, pushing water ahead and rising at the surface. These units have reportedly (9) been operated satisfactorily in cold climates.

The basic icing problem with a surface aerator is the ice buildup on the impeller shaft and supporting surface mechanism, with subsequent freeze-up and stopping of the mechanism. Figure 5 illustrates the type of problem which can be encountered. Mechanical surface aerators can and do ice up when climatic conditions cause the basin's contents to fall to temperatures of 0°C, and a heat-robbing wind is present.

Icing, or lack of it, is not entirely controlled by basic equipment design. It is a function of retention time, water temperature, incoming waste temperature, ambient dry and wet bulb temperatures, and wind speed. Under certain conditions, any aerator will ice. For mechanical surface aerators the external addition of heat to those areas, which from experience it has been found are apt to collect ice, and the minimization of exposed surfaces are the best techniques to control ice formation.

Cold weather mooring techniques applicable to either fixed mounted or floating units, similar to those shown in Figure 6, reduce the possibilities of sinking or turnover under adverse climatic conditions. These precautions should especially be used in aerated basins having long detention time and operating in cold climate conditions to insure continuous operation.

Theory

The presence of surface-active agents will have a marked effect on the oxygen-transfer rate as they affect both the liquid film coefficient K_L and the A/V ratio (surface area/volume) and hence K_La. This effect will be reflected by changes in concentration of surfactant and by changes in the turbulence and mixing in the system.

A surfactant will concentrate at an interface such that the interfacial concentration will be greater than that in the body of the liquid. As a result, a "film" of absorbed surfactant molecules is concentrated at the interface, which provides a barrier to diffusion of oxygen across the interface.

The changes in transfer rate in the presence of surface-active materials is defined by the coefficient, α, which is K_La (waste)/K_La (water). Increasing the concentration of surfactant will decrease α until the interfacial surface is saturated. Further increases will not affect α (Figure 7a). In bubble aeration, the presence of surfactants will markedly decrease the bubble size and hence increase A/V. Under these conditions, it is possible for α to increase in some cases to values greater than 1.0 (Figure 7b), because the increased effect of A/V exceeds the decrease in K_L caused by the surface barrier.

The degree of turbulence in the system will also effect α.

Under laminar conditions (approaching a stagnant film surface) there is substantially no effect on α because the resistance in the bulk of solution to oxygen transport exceeds the combined interfacial resistance (13). This condition would rarely be encountered in aeration practice. Under moderately turbulent conditions, a maximum depression occurs because the interfacial resistance to molecular diffusion by the absorbed surfactant molecules controls the transfer rate.

At high degrees of turbulence, α approaches unit as a result of the high surface-renewal rates, resulting in an inability to establish an absorption equilibrium at the interface (Figure 8). α often exceeds unity as a result of the increased A/V values associated with turbulent conditions at the surface and bubble entrainment (Figure 8).

The coefficient α can be expected to increase or decrease and approach unity during the course of bio-oxidation because the substances affecting the transfer rate are being removed in the biological process. In order to design the aeration system, the standard transfer efficiency (STE) is corrected for the waste conditions:

$$\text{Oxygen transfer in waste} = \text{STE} \frac{C_{sw}-C_L}{9.1} \cdot \alpha \cdot 1.02^{(t-20)}$$

Thimsen (14) has shown that under steady state conditions and relatively complete mixed conditions, the relationship between detention time, BOD removal efficiency, and the reaction or deoxygenation coefficient k, is as follows:

$$t = \frac{\frac{\text{inf. BOD}_5}{\text{eff. BOD}_5} - 1}{k_1}$$

Where: t = detention time, days

k_1 = reaction coefficient, aerated lagoon, complete mixed system, per day

The rate of biological oxidation in an aerated pond as represented by the value of the reaction coefficient k_1 is affected by temperature according to the following equation:

$$k_T = k_{20}\theta^{T-20}$$

Where: k_T = the reaction coefficient k_1 at temperature T^oC in the aerated pond

k_{20} = the reaction coefficient k_1 at 20^oC

T = temperature in aerated pond ^oC

θ = temperature coefficient (1.035)

The value of k_t and the desired percentage of BOD removal fixes the retention time. For domestic sewage, the value of k_t falls between 0.50 and 1.0. k_t values up to 3.0 have been reported for industrial wastes. A value of 0.5 is generally accepted as conservative design for cold climates and predicts a 75% BOD removal in 6 days with a 90% removal in 18 days. However, field observations have indicated higher removals, in fact, occur which can be attributed to normal bioflocculation characteristics of the sewage and to some apparent inaccuracies in this mathematical relationship at extremely low temperatures. For water climates, a value of 1.0 for k predicts a 75% removal in 3 days with a 90% removal in 9 days. For design accuracy, k_t should be determined from laboratory or pilot plant data which is especially important for cold climate applications.

The oxygen required by the microbiology to destroy a pound of BOD_5 is generally reported as a pound to pound ratio, L, e.g. 1.4 pounds of oxygen required per pound of BOD_5 destroyed. The actual oxygen requirement can be expressed as:

$$O_2 \text{ required hr.} = (L)\ (BOD_5 \text{ removed/hr.})$$

The oxygen requirements must be calculated for both summer and winter conditions.

The manufacturers of mechanical surface aerators usually report the efficiency of their equipment in terms of pounds of oxygen per horsepower hour under standard conditions of 20°C and 0 mg/l dissolved oxygen. To convert this figure to the pounds of oxygen per hour which may be transferred under pond conditions of temperature and dissolved oxygen, the following equation may be used:

$$N_m = N_o \frac{(C_{sw} - CL)}{C_s} \quad 1.02^{T-20} \cdot \alpha$$

Where: N_m = pounds of oxygen per hour transferred to waste by mechanical aeration

N_o = pounds of oxygen per hour transferred to pure water at 20°C and zero dissolved oxygen and atmospheric pressure of 760 millimeters of mercury

C_s = oxygen saturation of pure water in mg/l at 20°C

C_{sw} = dissolved oxygen saturation for waste in pond at surface pressure, and temperature in pond. $C_{sw} = \beta C_s$ where β may be 0.85 - 0.95

C_L = average dissolved oxygen in aerated lagoon.

T = temperature of lagoon, °C

α = ratio of over-all oxygen transfer coefficient of aeration equipment in waste to that in water

The relationship between the efficiency of oxygen transfer at pond conditions to the efficiency of oxygen transfer at standard conditions for diffused air aeration in aerated ponds may be represented as follows:

$$E_L = \frac{E_s(C_{sm}-C_L)}{C_s} 1.02^{T-20}$$

Where: E_L = percent oxygen transfer efficiency at pond conditions

E_s = percent oxygen transfer efficiency at standard conditions, 20°C, zero DO

C_{sm} = oxygen saturation of waste in pond at mid-depth and temperature of pond $C_{sm} = \left(\frac{P_b}{29.4} + \frac{O_t}{42}\right)$

Where: P_b = absolute pressure of air at depth of diffusers in psia

O_t = percent oxygen by volume in air leaving pond surface based on assumed absorption efficiency

The horsepower requirements are established based on:

hp = (N_m)/(aerator transfer capacity, lbs O_2/hp-hr)

Although it is not necessary to maintain scouring velocities and the suspension of all solids in an aerated lagoon, it is imperative to provide sufficient power to accomplish a complete mixing of the liquid and to maintain a uniform dispersion of dissolved oxygen throughout the lagoon. In dealing with dilute wastes and wastes of weak strength, especially in lagoons having long retention times, it is quite common for the horsepower requirements for mixing to exceed the horsepower required for aeration.

Basin mixing energy requirements have been established for basins for influent BOD_5 as high as 600 mg/l, in which mixing energy is related to aerator unit horsepower, basin depth, and volume, by the data presented in Figures 9 and 10 (12). The argument regarding the most effective type of mechanical surface mixer has been summarized by Kalinske as follows (15):

(a) Mixing is a turbulent diffusion phenomenon

(b) Turbulent diffusion can be characterized as proportional to the velocity of the stream and its relative size.

(c) The velocity at a remote point from the turbulent source can be increased more efficiently by increasing the flow at the source or less efficiently by increasing the velocity at the source

(d) Large, slow moving impellers have a larger source flow per horsepower than small, fast moving impellers

(e) Therefore, large slow moving impellers are more efficient mixing devices than small fast moving impellers.

Kalinske carried the argument further showing that large slow moving impellers are more efficient mixing devises than is gas mixing.

The most extensive investigation on solids accumulation to date in cold climate aerated lagoon operation have been carried out in the Winnipeg study (9). Accumulation and removal of these solids was considered a major problem. It is believed the decomposition of these solids was occuring at a slower than expected rate due to the cold climate conditions. It appeared the net solids accumulation was occuring at a rate of approximately one ton of dry solids per Imperial mgd treated. During the summer months there was a decline in BOD removal efficiency accompanied by a trend to reduced dissolved oxygen concentration in the lagoon. This reduced dissolved oxygen concentration was believed to be caused by high oxygen demands imposed by the end products of anaerobic sludge decomposition in the bottom of the lagoon.

The liquid temperature in the aerated lagoon depends upon the temperature of the incoming wastewater, the ambient temperature and wind factor, the organic loading, and required detention time, and the heat contribution, if any, from the aeration equipment. Assuming a light breeze across a completely mixed aeration lagoon surface free of ice or extensive foam cover and aerated by conventional mechanical surface equipment, the heat balance can be expressed as follows (16):

$$T_i - T_w = \frac{(T_w - T_a)\ f\ A}{Q}$$

Where: T_i = influent waste temperature (^oF)

T_w = lagoon temperature (^oF)

T_a = air temperature (^oF)

Q = wastewater flow (MGD)

A = lagoon surface area (ft^2)

f = proportionality factor

The proportionality factor includes the heat transfer coefficient, wind, and humidity effects. The value of f is approximately 12×10^{-6}.

Figure 11a and 11b shows the maximum allowable detention time to prevent the liquid temperature from dropping below 2°C and the BOD reduction based of operational data that can be realized at 2°C liquid temperature, respectively, for a 20 ft deep aerated basin receiving a winter sewage influent at 6°C.

Seasonal changes affect both the bottom sludge activity and the BOD reduction rate in the liquid effluent. On a seasonal basis these two factors are interrelated. The bottom sludge receives very little, if any, biological degradation during the winter. During the summer, methane from the bottom deposits is produced during late July and August. These gas emissions are virtually non-existent below 4°C (17). In many wastewater treatment plants these sludge deposits are deepest near the influent discharge point. The extent of this problem can be reduced or eliminated by proper introduction of the liquid influent near the point of aeration and elimination of "dead" mixing zones where large accumulations of solids can deposit. Proper mixing can control uniform solids deposition. This will greatly reduce the summer anaerobic activity which causes resuspending of sludge and the creation of large additional oxygen uptake demands and eventually leveling out the bottom sludge deposition.

Field Observations and Design Considerations

Besides municipal aerated lagoon installations in Alaska, Canada and the North Central United States extensive evaluation of cold climate aerated lagoon applications have been reported for municipal and industrial applications in other cold climate areas of the world, notably Scandinavia.

It is especially in the area of industrial waste treatment that the aerated lagoon has found favorably application when operating under cold climate conditions.

The major factors contributing to these successes include greater heat contributions in the incoming wastewaters, higher biological reaction rates and bioflocculation phenomena, and freedom from regulatory restrictions permitting the Engineer to develop a system which will perform satisfactorily under unusual conditions. Conversely, some municipal installations have attempted to adapt successful industrial designs and met with failure because of an incomplete understanding of the problem.

One of the most interesting cold climate installations is the aerated lagoon treating pulp mill wastewater at Kemijärvi, Finland, shown in Figure 12. This installation is located at the only free world pulp mill North of the arctic circle. Although the Figure shows the basin and aeration unit almost completely covered with ice and frozen foam, the unit operated with detentions of 5 to 6 days at air temperature down to -45°C while obtaining BOD_7 reductions similar to those reported in Figure 11b.

Any consideration of wastewater purification under cold climate conditions should consider alternative treatment possibilities. An important feature of this approach is the provisions for a second stand-by treatment system should the first fail for any reason. This is especially important when two distinctly different seasonal conditions exist.

For example, heat losses in an aerated lagoon can be minimized by providing separate equipment to achieve oxygenization and mixing as illustrated schematically by the Alternative A (modified) as shown in Figure 13. During winter operation the lower oxygen uptake requirements can be met with an auxiliary external in-line oxygenation device and subsurface mechanical mixing provided to disperse the oxygen and biological solids throughout the basin contents. A shallow tube sedimentation unit is located near the discharge outlet to automatically return settled biological solids to the aeration basin. Such an arrangement will result in a low level activated sludge system while minimizing heat loss and thus permit shorter winter detentions to meet BOD reduction objectives.

Another distinctly feasible approach for seasonal solutions is summer aerated lagoon operation followed by winter chemical treatment. Under these conditions the summer operation can be designed to achieve 85-90 percent BOD_5 reductions with winter chemical treatment achieving up to 60 percent BOD removals and high nutrient reduction. The chemical treatment is less affected by low temperatures compared to biological treatment (18). Also, it normally takes several days to bring a biological treatment plant into good operation after a process disturbance, whereas, it takes only hours for a chemical plant. The winter chemical sludge can be allowed to freeze in a seepage lagoon and back covered after draining during the following summer.

In the two alternative cases described above, initial construction cost will be somewhat higher because of the duel systems, however, high winter maintenance cost can be reduced and operational reliability may be improved.

These, or similar, design alternatives must be made in those cases which do exist under the most severe of cold climate conditions where it is impossible to design and operate a mechanical surface oxygenated aerated lagoon to meet both BOD removal performance requirements and process reliability requirements. In some cold climate cases a conventionally designed aerated lagoon simply will not work. The limitations under which a surface aerated lagoon will operate can be estimated using the information presented in Figure 11.

The cost of cold climate wastewater treatment requires special concern. In some areas, especially small northern communities, labor and utility power is difficult to obtain or extremely expensive. Power may cost as much as $0.25 to $1.00 per Kwh (5) and labor correspondingly high. Thus, normal ratios between capital charges and operating cost or similar cost concepts simply will not hold. Generalities are not sufficient to comment on, but, it can be stated that local cost conditions must be evaluated.

Under the normal conditions existing in most of North America aerated lagoon construction cost is approximately 2/3 and operating cost approximately 1/2 that of an activated sludge system to meet the equivalent level of BOD removal. The cost of mechanical/chemical treatment plants is about 4/5 that of conventional activated sludge while operating cost will be higher. Such considerations are valid for treatment plants for greater than 5000 persons. Construction cost of smaller chemical treatment plants can be higher than activated sludge plants.

It is good economy to invest more in equipment and automatic control to reduce the operating cost. The simplicity and low operator attention normally required for aerated lagoons make it especially attractive where labor rates for operation are very high.

Figure 14 shows the capital cost of the aerated lagoon process per unit of lagoon capacity based on Winnipeg, Canada, conditions. These cost are based on an Engineering News Record Sewage Treatment Plant Index of 228 updated to March 1972 conditions. As costs change, the appropriate adjustment must be made to the cost.

Figure 15 shows the range of operating and maintenance cost for similar conditions. In these cases local power was estimated at 1.00¢ per kw - hr and labor at $5.00 per hour. The power cost was estimated at being about 1/3 of the total operating cost. Local cost conditions may differ drastically.

A design example will be considered to present the approach and problem solving logic used in process selection. A community located in a cold winter climate will be considered with a future winter design sewered population of 2000 and approximately 3000 summer inhabitants having sewerage collection for the design period. The community is situated on alluvial plains with a creek, into which treated sewage will be discharged, passing through the town. Long term population projections are difficult to make but additional land will be reserved for treatment expansion according to future needs.

The aerated lagoon has been selected for treatment process consideration in this community because of its upgrading flexibility in uncertain long term design considerations, lower capital and operating cost, available land, simplicity of operation, and its proved ability to meet BOD removal requirements of 85 percent in summer and 60 percent in winter established and projected for the community.

Evaluation of soil conditions on the site were made by a local geological engineering firm familiar with local construction. The basin depth of 20 feet, freeboard, and landscaping were selected to insure adequate protection against winds excessively influencing heat loss from the pond surface. Interior pond corners will be rounded. The pond will be lined with a 6-inch clay blanket to minimize seepage. A stock-type fence will encompass the plant facility as needed with a locked access gate provided.

The sewage treatment plant design criteria follows:

	Summer	Winter
Flow volume	0.3 mgd	0.2 mgd
BOD_5	750 lbs/day	500 lbs/day
	300 mg/l	300 mg/l
BOD_5 reduction required	85%	60%
	640 lbs/day	300 lbs/day
Minimum basin D.O.	2 mg/l	2 mg/l
Air temperature	20°C	-20°C
Sewage influent temperature	10°C	6°C
Lagoon temperature extreme	15°C	2°C
$K_{20°C}$	0.75	

The design calculations follow:

Retention time:

summer: $K_{15} = 0.75\ (1.035)^{15-20} = 0.62$

$$t = \frac{\frac{300}{45} - 1}{0.62} = \frac{5.67}{0.62} = 9.1 \text{ days}$$

winter: t = 2.5 days for 60 percent BOD_5 reduction

Use Figure 11b since the conventional temperature correction parameter has not always been shown applicable for field performance in extreme cold weather conditions. Therefore, emperical field data correlation is method of choice.

required pond capacity:

summer: 9.1 x 0.3 = 2.7 mg

winter 2.5 x 0.2 = 0.5 mg

oxygen requirements:

summer 1.4 x 640 = 900 lbs O_2/day

winter 1.4 x 300 = 420 lbs O_2/day

hp requirements for oxygen, (includes α correction, etc.)

summer 900 ÷ (2.5 x 24) 15 hp

winter 420 ÷ (1.9 x 24) 9 hp

hp requirements for mixing, consider Figure 13, winter alternative B

From Figure 10, maximum allowable dimension = 60 ft x 60 ft @ 20 ft depth; OK

From Figure 11, .022 hp/1000 gal = 11 hp @ .5 mg (winter); OK, 10hp provided

Winter heat loss

From Figure 11 - for 2.5 days detention and air temperature at -20°C, the basin can be expected to cool to about 2°C.

The system selected then would operate as shown in Figure 13, Alternative B. When air average temperatures dropped significantly below -20°C. The Alternative A mode of operation can be used down to temperatures of -60°F. In this case the biological seed in Alternative B basin can be pumped to Basin A without destroying the biological activity.

Optional auxiliary equipment for basin Alternative A winter operation would include a mechanical mixer and in-line aerator.

Tube settling columns would be used at the discharge in either Alternative A or B to increase the active biological mass in the aeration basin and thereby increase the BOD reduction efficiency. This total system would be flexible, allow for possible treatment plant expansion if population growth or effluent quality requirements dictated and represents one possible approach to the low cost solution of a cold climate biological wastewater treatment problem.

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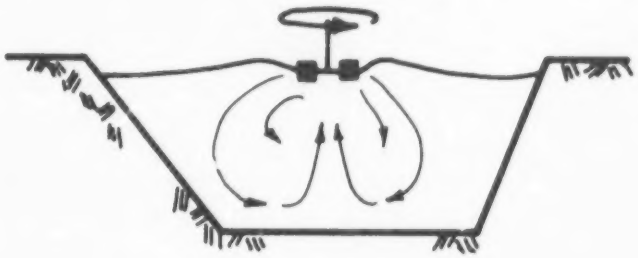
FIGURE 1 - THE FIRST AERATED LAGOON TREATING MUNICIPAL EFFLUENTS IN THE U.S.A.

FIGURE 2 – AN EARLY SERIES CELL AERATED LAGOON INSTALLATION

COMPLETELY MIXED AERATED LAGOON



FACULTATIVE AERATED LAGOON

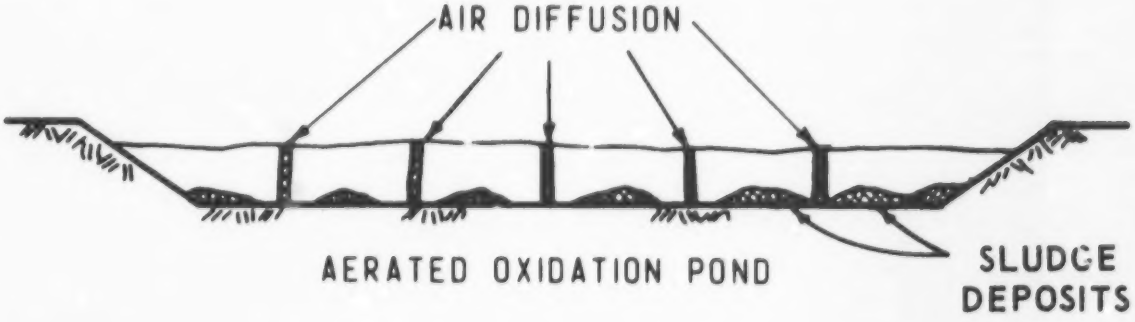
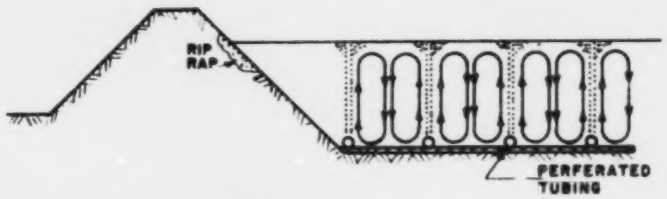
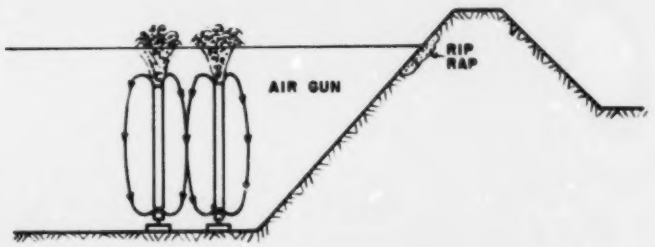


FIGURE 3

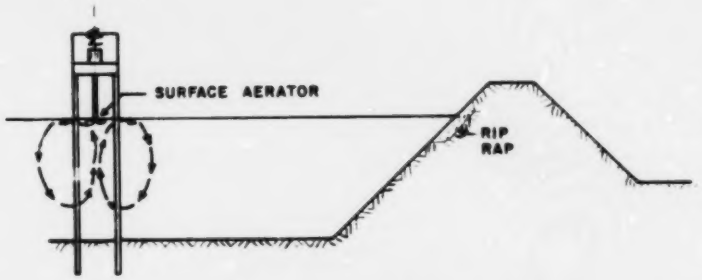
EKONO	DIFFERENT TYPES OF AERATED LAGOONS	Proj. leader H.J.E. Date MAR. 16, 1972
		Dwg. No.



A PERFERATED TUBING



B AIR GUN



C SURFACE AERATOR

FIGURE 4

EKONO	AERATED LAGOON PROCESS EQUIPMENT DETAILS	Proj. leader HJE	Date MAR. 14, 1972
		Dwg. No.	

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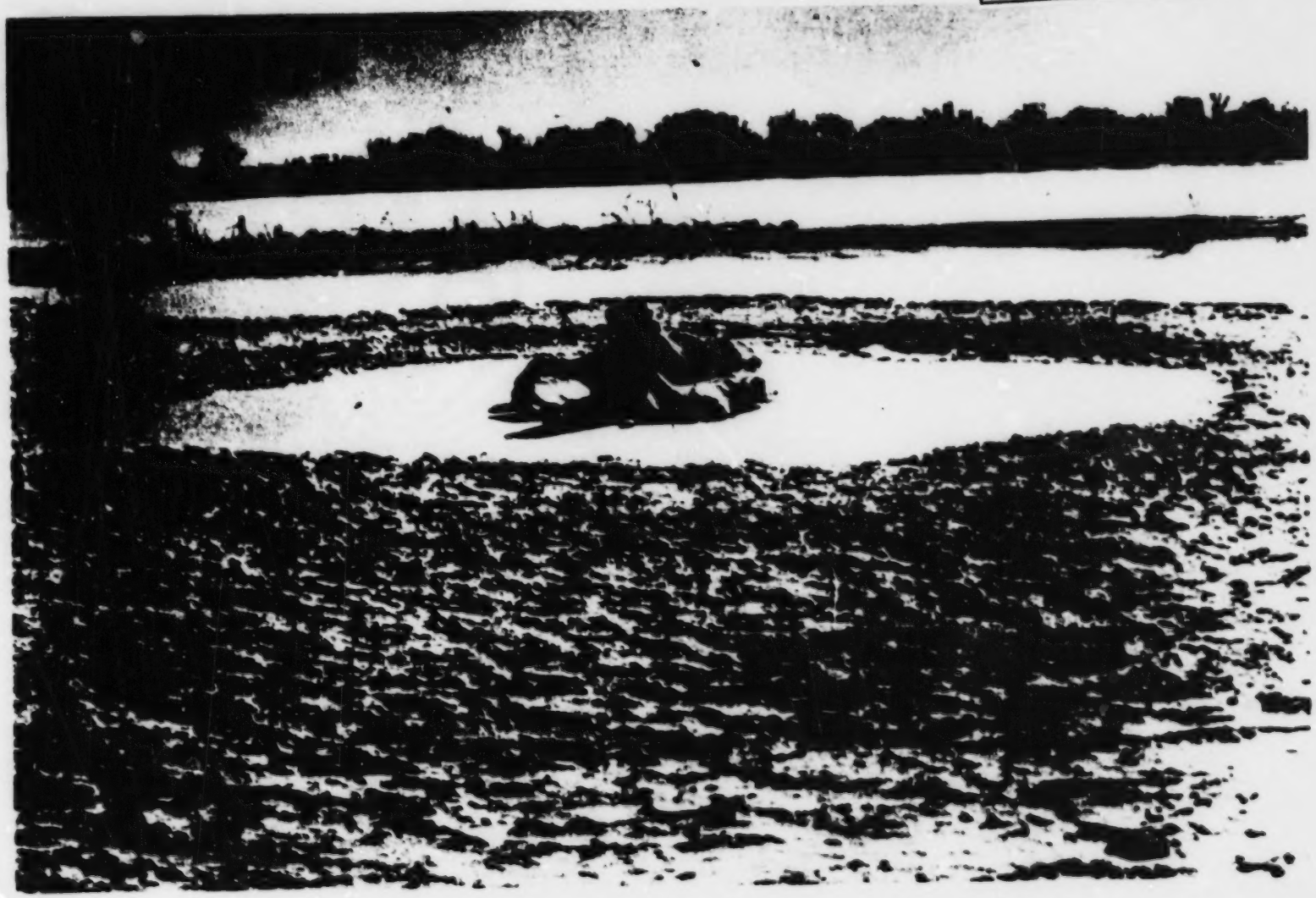


FIGURE 5 – MECHANICAL SURFACE AERATOR SUBJECTED TO EXTREME COLD CLIMATE

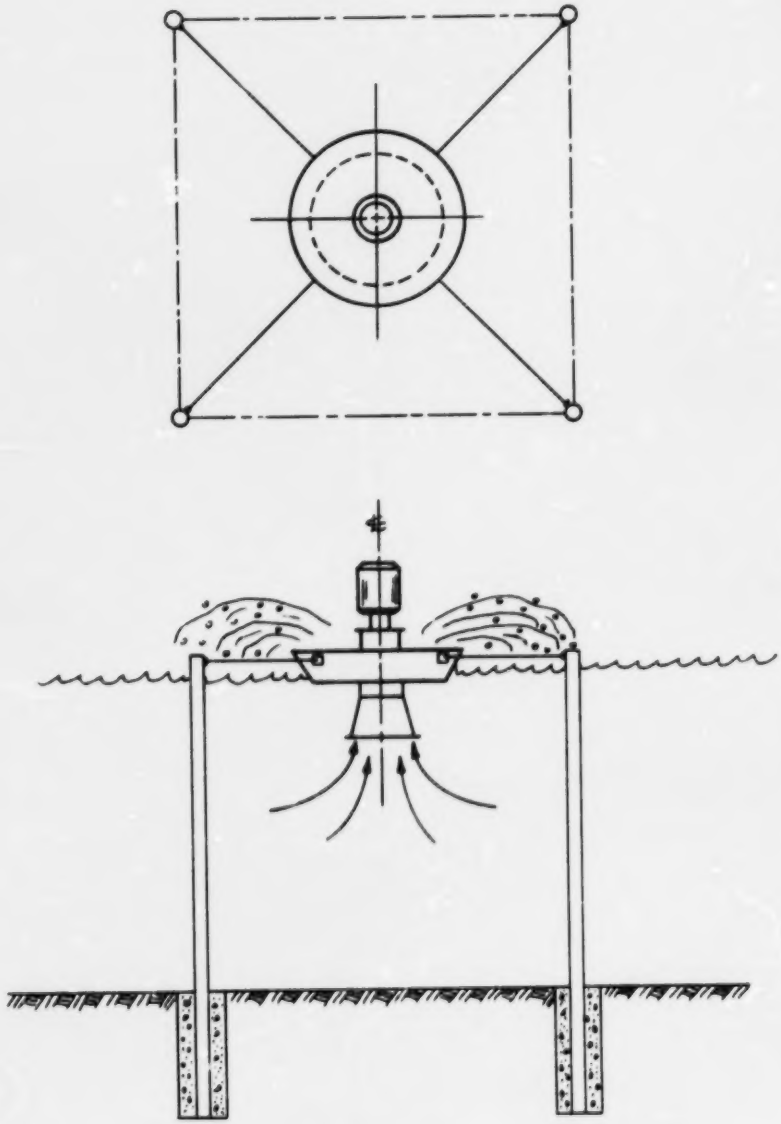
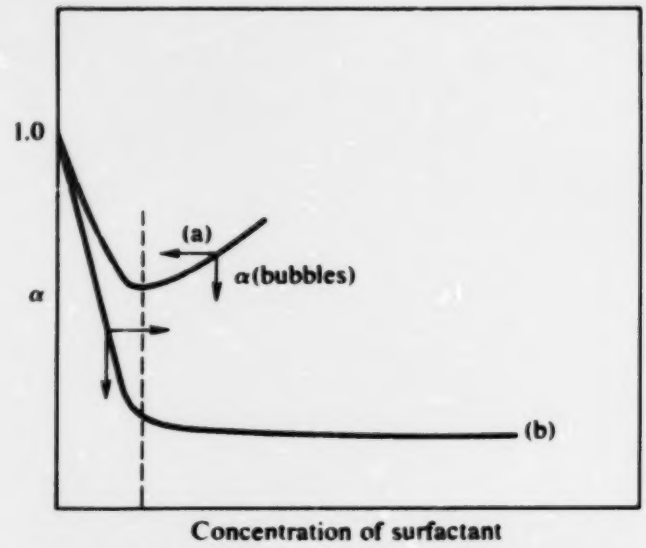


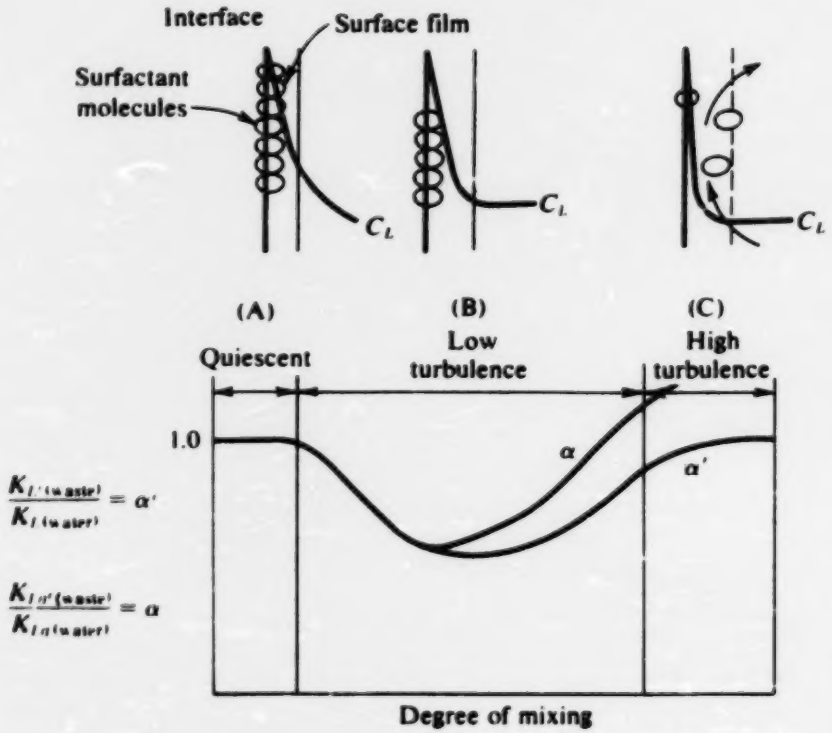
FIGURE 6

EKONO	COLD WEATHER MOORING TECHNIQUES	Proj. leader H.J.E.	Date MAR 16,1972
		Dwg. No.	



Effect of concentration of surfactant on oxygen transfer.

FIGURE 7



Effect of turbulence on oxygen transfer.

FIGURE 8

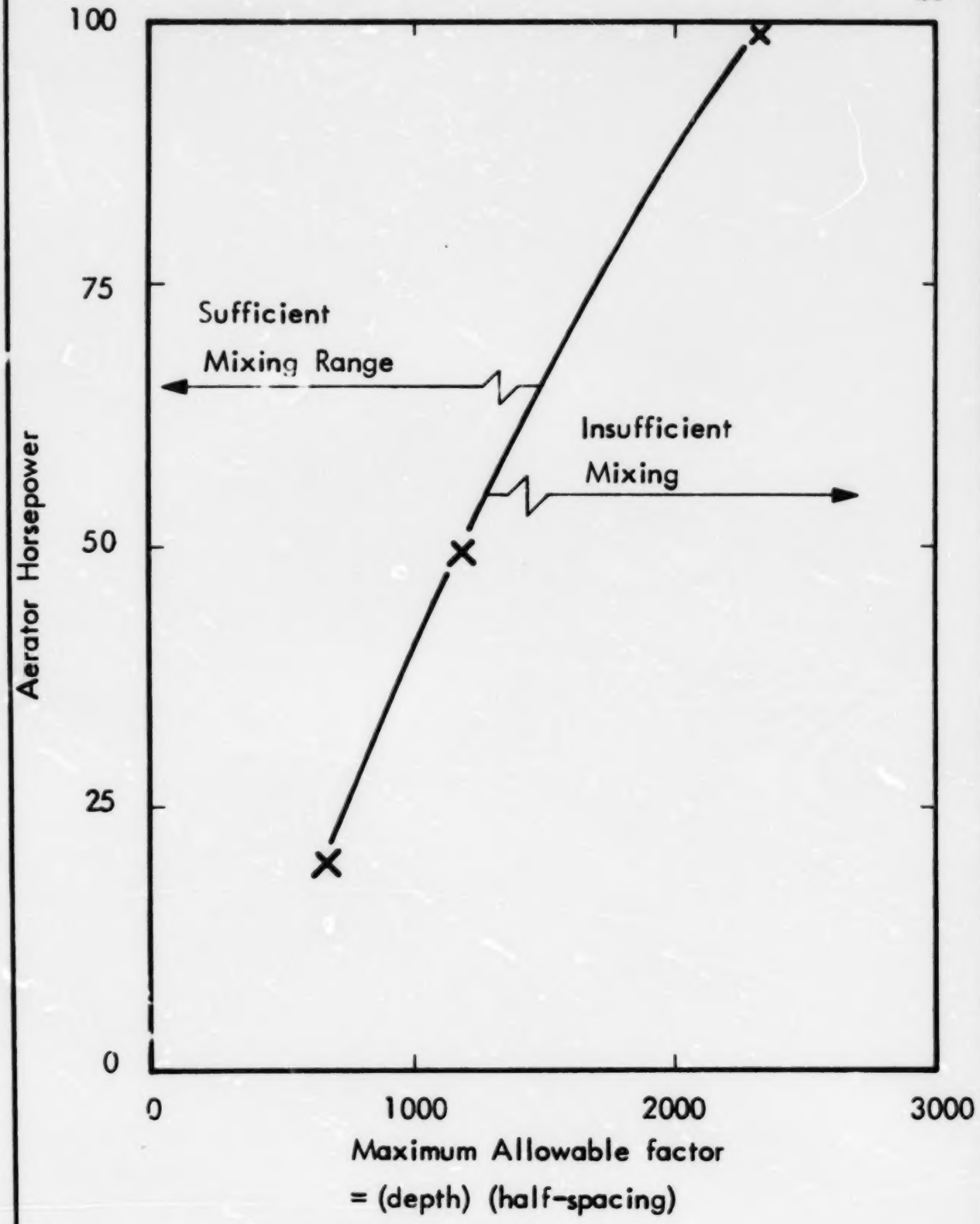


FIGURE 9

EKONO	ALLOWABLE AERATOR SPACING AS RELATED TO AERATOR SIZE AND BASIN DEPTH	Proj. leader H.J.E. Date MAR. 16, 1972
		Dwg. No.

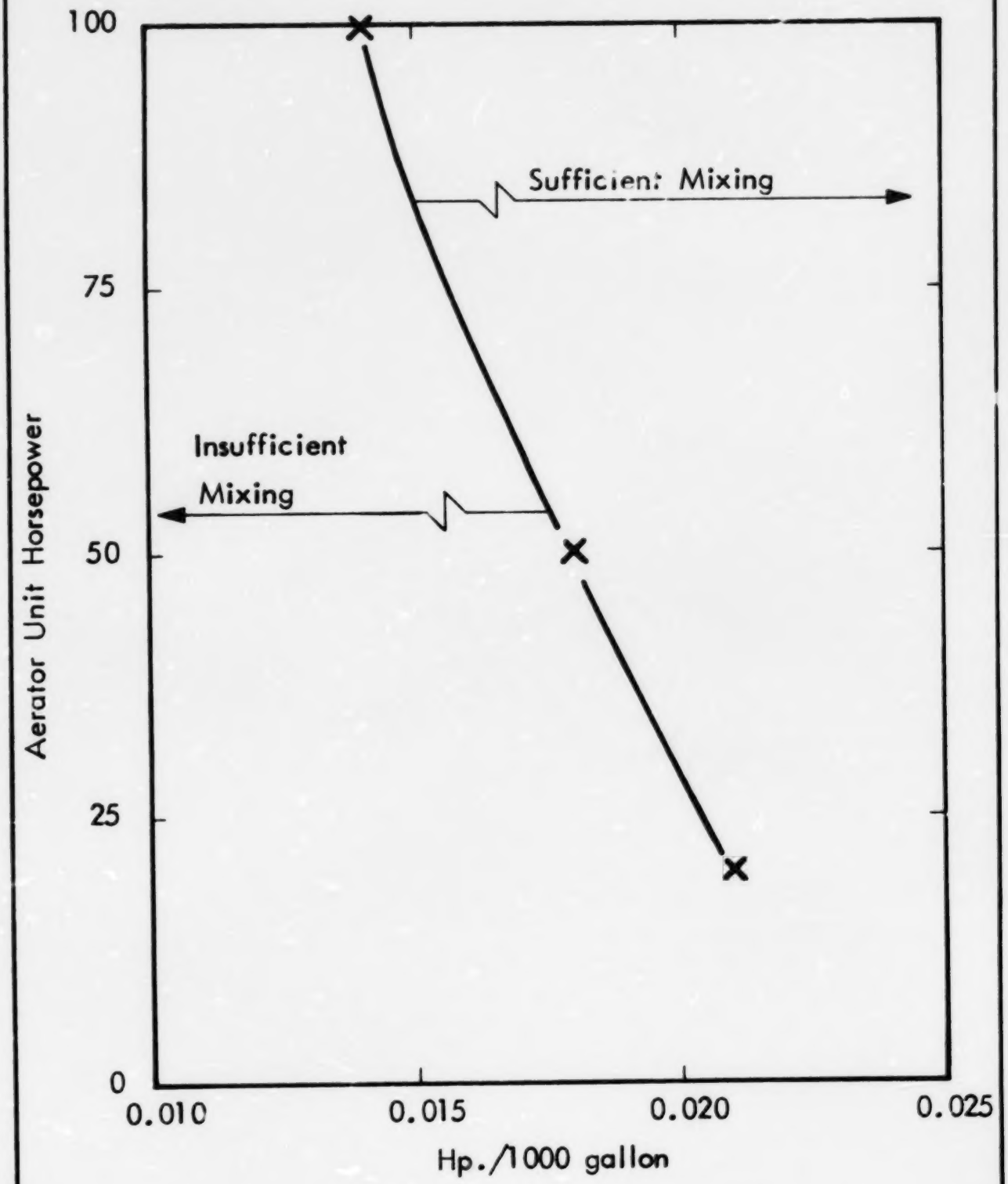


FIGURE 10

EKONO	MIXING ENERGY REQUIREMENTS FOR MECHANICAL SURFACE AERATION UNITS	Proj. Leader H.J.E. Date MAR. 16, 1972 Dwg. No.

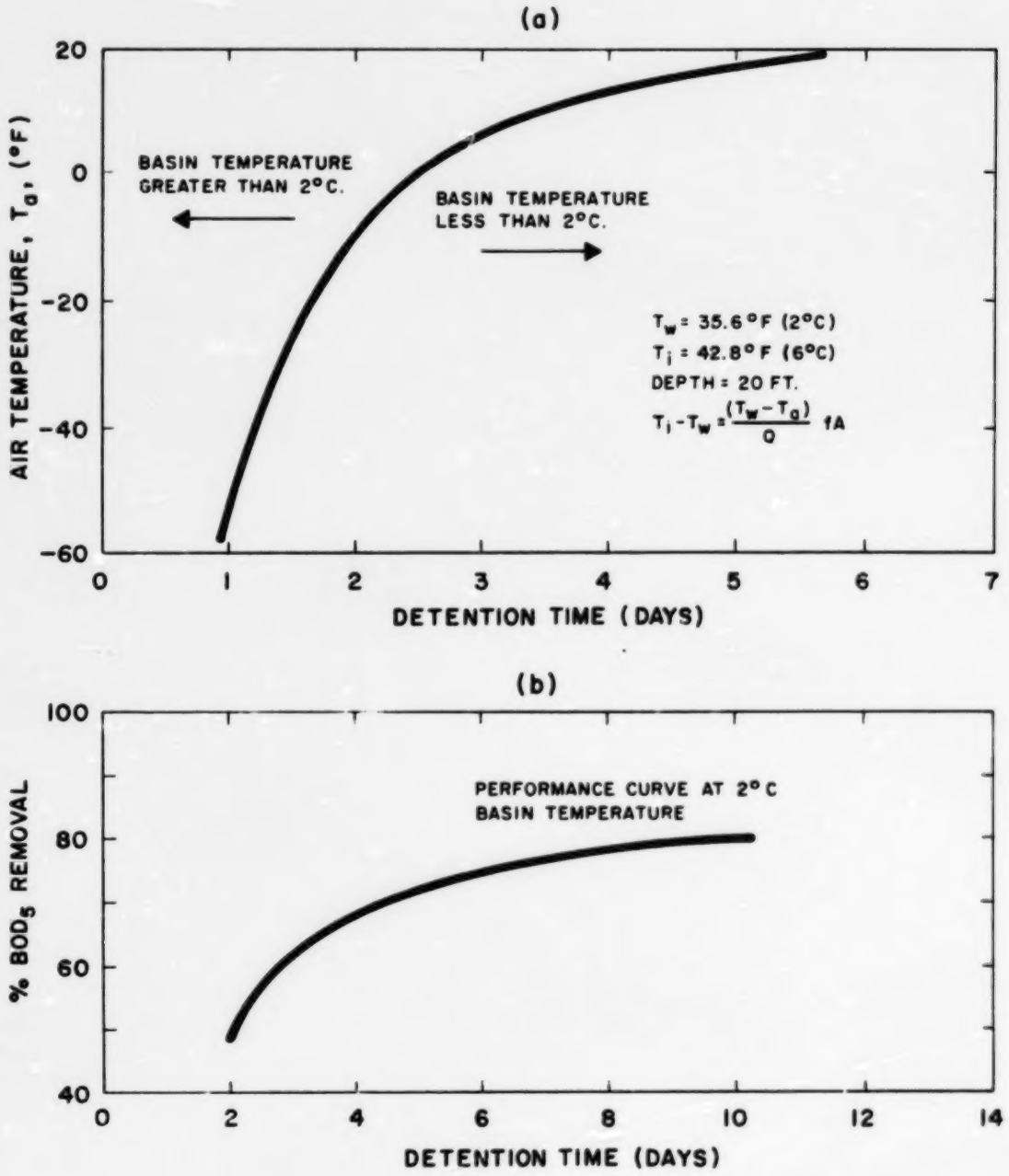
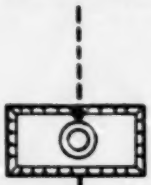


FIGURE 11

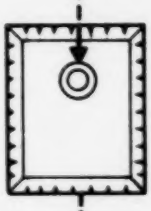
EKONO	OPERATION EXPECTATIONS OF AERATED LAGOON IN COLD CLIMATE CONDITIONS.	Proj. leader H.J.E. Date MAR. 14, 1972 Dwg. No.

FIGURE 12 –SCANDINAVIAN AERATED LAGOON IN OPERATION NORTH OF THE ARCTIC CIRCLE WITH LAGOON SURFACE COVERED MAINLY WITH FROZEN FOAM

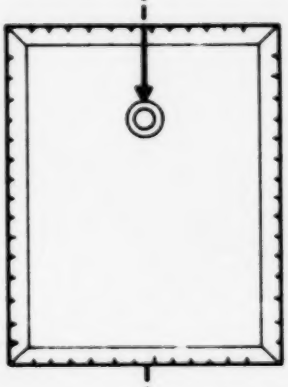
SUMMER OPERATION



1-5 HP AERATOR
d = 0.67 DAYS
V = 0.2 mg



1-5 HP AERATOR
d = 1.67 DAYS
V = 0.5 mg

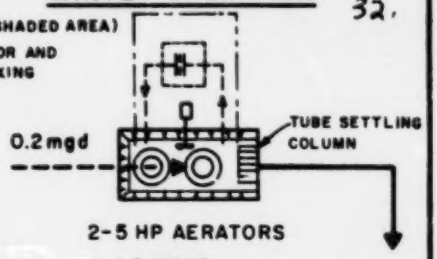


1-5 HP AERATOR
d = 6.7 DAYS
V = 2.0 mg

RECIPIENT - 85% BOD_5 REDUCTION
0.1 DAYS RETENTION
0.3 mgd

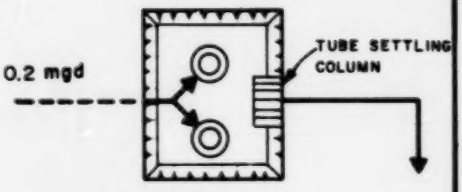
WINTER OPERATION

OPTIONAL (SHADED AREA)
IN-LINE AERATOR AND
MECHANICAL MIXING



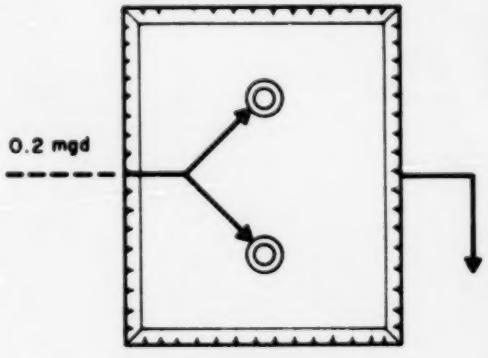
2-5 HP AERATORS
d = 1.0 DAYS
OPERATES TO -50°F (AIR)
BOD REMOVAL @ -50° > 40%

ALTERNATIVE A



2-5 HP AERATORS
d = 2.5 DAYS
OPERATES TO 0°F (AIR)
BOD REMOVAL @ 0° > 60%

ALTERNATIVE B

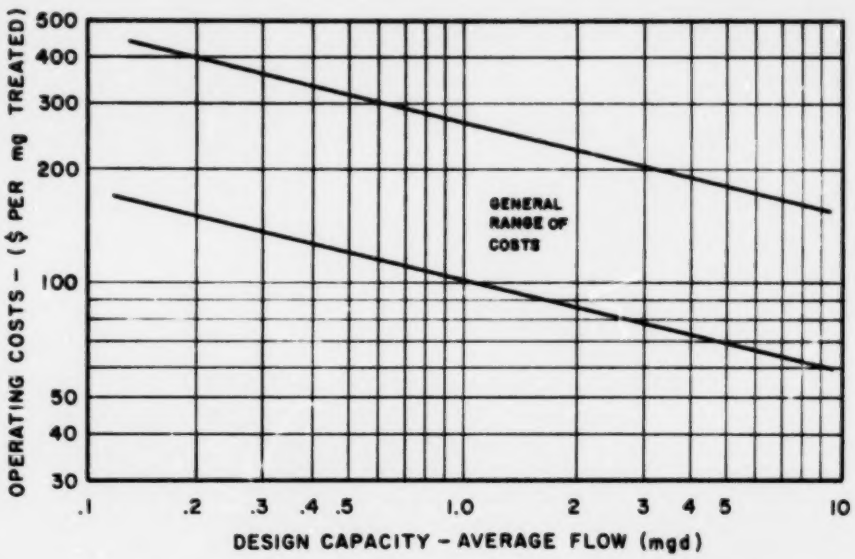


2-5 HP AERATORS
d = 10 DAYS
OPERATES TO 20°F (AIR)
BOD REMOVAL @ 20°F > 75%

ALTERNATIVE C

FIGURE 13

EKONO	CASE EXAMPLE AERATED LAGOON PERFORMANCE ALTERNATIVES	Proj. leader H.J.E.	Date MAR.14,1972
		Dwg. No.	

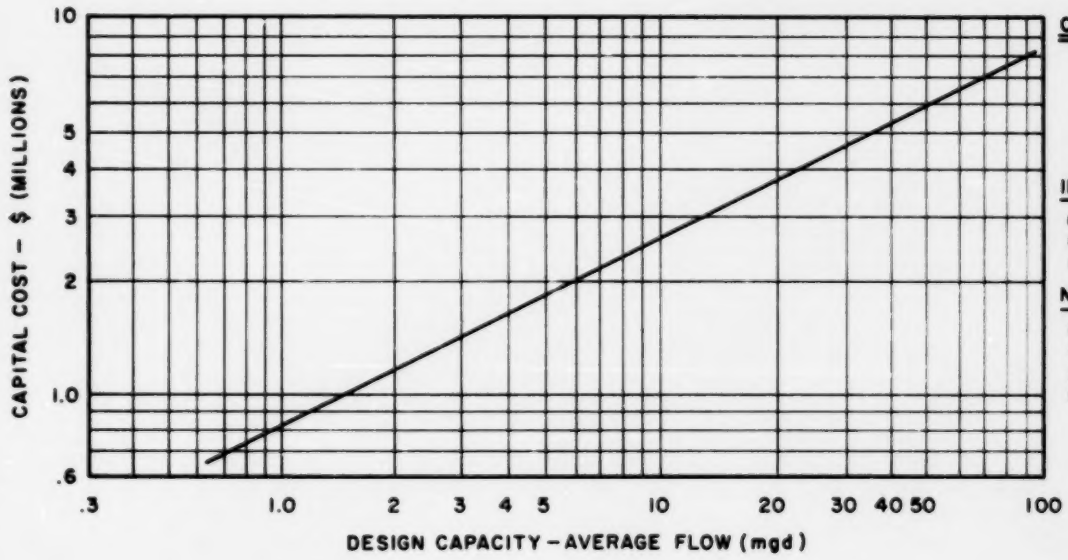


COSTS (ENR STD INDEX 228, BASED ON MARCH, 1972)

INCLUDED:

(1) POWER, EQUIPMENT AND PARTS.
(2) LABOR (INCLUDES 23% FOR OVERHEAD).
(3) MAINTENANCE
(4) LABORATORY
(5) CHLORINATION
(6) 3% FOR DIKE & ROAD MAINTENANCE
(7) PUMPING

FIGURE 15, OPERATION AND MAINTENANCE COSTS



COSTS (ENR STD INDEX 228, BASED ON MARCH, 1972)

INCLUDED:

10% ENGINEERING & CONTINGENCIES ON ACTUAL COST.

NOT INCLUDED:

OUTFALL, LAND, PUMPING STATION AND BLOWER HOUSING

FIGURE 14, CAPITAL COST vs DESIGN CAPACITY

EKONO	AERATED LAGOONS	Proj. leader H.J.E.	Date MAR.14,1972
		Dwg. No.	